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Background: Ultrasound elastography techniques allow measuring quantitatively the viscoelastic properties of soft tissue. Nevertheless, most of them are restricted to small deformation [1], while soft tissues exhibit strong non-linear elastic behavior under large deformation. Little work is currently available in the literature on the *in vivo* quantification of non-linear parameters of soft tissues [2]–[5].

Aims: The aim of this study is to develop a method for estimating non-linear elastic parameters of soft tissues. The method relies on the coupling between ultrasound displacement imaging and indentation. By the use of numerical model identification, the non-linear elastic parameters are non-invasively extracted.

Methods: The approach can be described in three main steps (fig 1).

i. Indentation process: a 9 MHz ultrasound linear probe (*L12-5 50mm, Philips healthcare, NL*) is used as indenter to generate large deformations (~20% of strain with maximal strain rate of 0.1 s^{-1}) in the tissue. The probe is attached to a robotized prototype and a force sensor is used to measure the force (6 axis Force/Torque sensor *Nano17, ATI Industrial Automation, NC, USA*) applied by the indenter to the tissue.

ii. Imaging part: the same ultrasound probe is used to acquire beamformed radiofrequency (RF) signals during the indentation at a frame rate of 500 Hz, using a plane wave beamforming sequence with an acquisition system (*Verasonics Inc., WA, USA*). 2D displacement fields are computed offline using a normalized cross correlation algorithm [6].

iii. Identification process: the indentation experiment is simulated numerically using a commercial finite element software (*Abaqus Simulia, Dassault Systèmes, FR*). Tissue behavior is modeled using a hyper-elastic model (Neo-Hookean) and 2D displacement maps are computed subsequently. The identification of Neo-Hookean parameters is performed through minimization of the error between the experimental and the numerical displacement fields using the simplex algorithm [7].

To validate this method, an experiment on a polyvinyl alcohol hyper-elastic cryogel was conducted. Hyper-elastic properties were compared to those obtained with rheometry tests (uniaxial compression) as the ground truth.

Results: By application on a controlled gel phantom and comparison with classical rheometry measurements, we showed that the proposed method provides a good estimation of the non-linear behavior (hyper-elastic) parameters of the soft materials.

Conclusions: The proposed method enables the characterization of the non-linear mechanical properties of soft tissues for large deformations, such as liver tissue, non-invasively. The quantitative rheological models of liver elasticity could then be used to improve the numerical liver models used in surgical simulators. While here applied for Neo-Hookean hyper-elasticity, this technique thought to be applied for the characterization of a large variety of soft tissues by specific complexifications of the identified model.

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References: **[1]** J Vappou 2012, *Crit. Rev. Biomed. Eng.* 40(2), 121-34 **[2]** Oberai *et al.* 2009, *PMB* 54(5), 1191-207 **[3]** Hall *et al.* 2009, *Proc. EMBS IEEE Conf.* 1967–70 **[4]** Renier *et al.* 2007, *Proc. IUS IEEE* 554–7 **[5]** Bernal *et al.* 2016, *IEEE UFFC* 63(1), 101–9 **[6]** Viola *et al.* 2003, *IEEE UFFC* 50(4), 392–401 **[7]** Nelder *et al.* 1965, *Comp. J.* 7(4), 308–13.

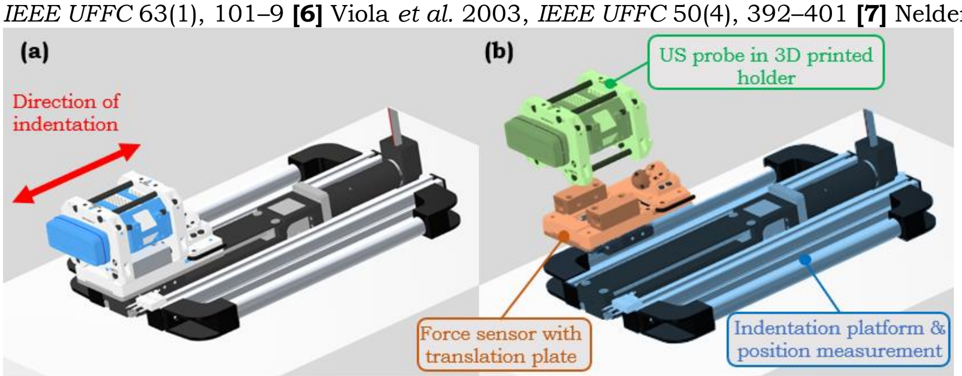

Figure 1: Indentation Prototype
(a) fully assembled view
(b) exploded view